WinFS Storage Architecture

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03/02/2004

WinFS

WinFS ECS Talks

Overview	Quentin Clark
Data Model and Programming Model	Anil Nori
API	Mike Deem ←**rescheduled**
Architecture and Implementation	**Nigel Ellis**
Schema	J. Patrick Thompson
Rules Engine	Praveen Seshadri
File System Integration	Sanjay Anand
Sync	Lev Novik

Overview

Covered:

- Basic WinFS architecture
- Deep drilldown into the data model, storage API and implementation
- Details of database features and usage
- Schema development and deployment
- Operations: create-find-update-delete

Not Covered:

- Sync, Rules or Utilities
- Deep details of every WinFS component

- More detailed talks on each component in future ECS talks

What is WinFS?

- WinFS is a rich information store which ships as part of Longhorn
- Data is organized around the concepts of Items, Extensions and Relationships
- This organization is performed in the context of the WinFS data model

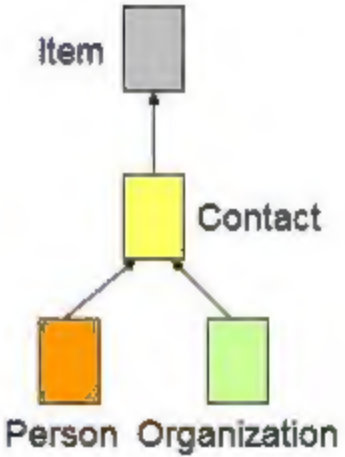
WinFS Data Model

- The WinFS Data Model describes
  - the shape of the data stored in WinFS
  - the constraints on the data
  - associations between data
- WinFS world is comprised of items, relationships and extensions
- Items are the primary objects that applications work on
- Items can be associated with other items via relationships
- Items can be extended with extensions (or subclass)

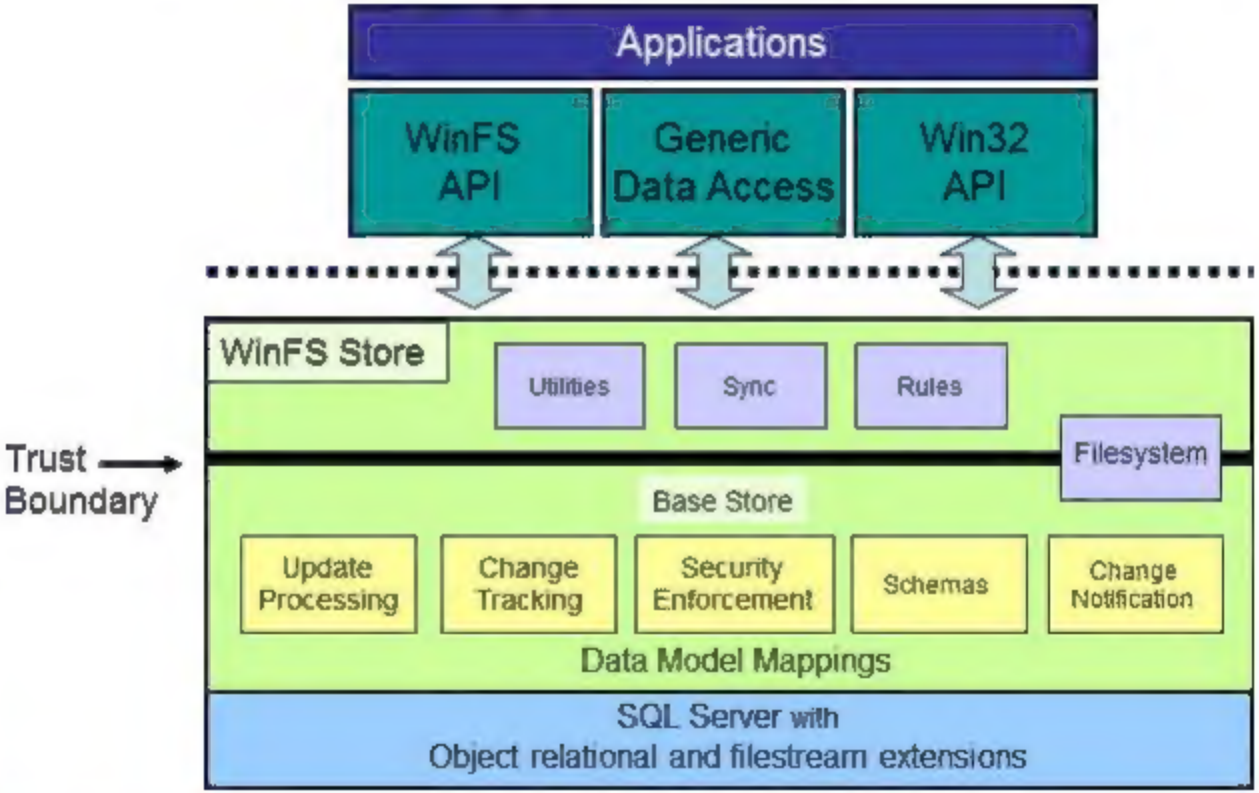
WinFS Type Example

```
using Contact = System.Storage.Contact;
using Core = System.Storage.Core;
using Base = System.Storage;

type Contact.Address : Base.NestedType {
   string Street;
   string City;
   string Zip;
   …
}
type Contact.Person : Core.Contact {
   datetime BirthDate;
   binary[] Picture;
   Address BirthAddress;
   MultiSet<Address> Addresses;
   …
}
type Contact.Organization : Core.Contact {
   string OrganizationName;
   …
}
```



WinFS Layers



SQL OR Extensions

- WinFS leverages object relational extensions in SQL
- Importing of CLR types into SQL type system
  - Supports single inheritance
  - Type substitution
  - Collections (ordered and un-ordered)
- Objects can be larger than 8K (internal DB page size)
- Lazy materialization
  - Delayed access to object LOB properties
  - Allows you to fetch the Person without the Picture
- Optimizer extensions
  - Indexes on structure paths – Person.Address.City
  - Indexes on nested collections – Person.Offices.Bld
  - Stats on type hierarchy, structured paths, and nested collections

SQL OR Extensions - Smart Serialization

- SQLCLR types leverage a custom serialization library (SL)
- Efficient access to properties of embedded objects
  - Avoids object construction or method invocations for simple property getters and setters
  - Property and field access translates to compiled field accessors
- New structured serialization format
  - Understands inheritance, embedded types, collection types
  - Internal to SQL
- Provides "record like" performance for accessing object properties

SQL OR Extensions - Smart Serialization

- Example:

```
SELECT FirstName, LastName, …
FROM [System.Storage.Contact.Store].Contact c
WHERE BirthAddress.City = 'Seattle'
```

- Fetching HomeAddress.City does not require the materialization of the Address object
- Properties retrieved by directly "cracking" the serialized form

SQL OR Extensions - Collections

- SQL supports a generic collection type MULTISET<T>
- Properties can be declared using collections
- Treated from SQL as "nested table"
- Queryable using UNNEST table valued function

```
SELECT c.FirstName, c.LastName,
       A.addr.City, A.addr.Zip
FROM [System.Storage.Contact.Store].Contact c
CROSS APPLY UNNEST(c.Addresses) AS A(addr)
```

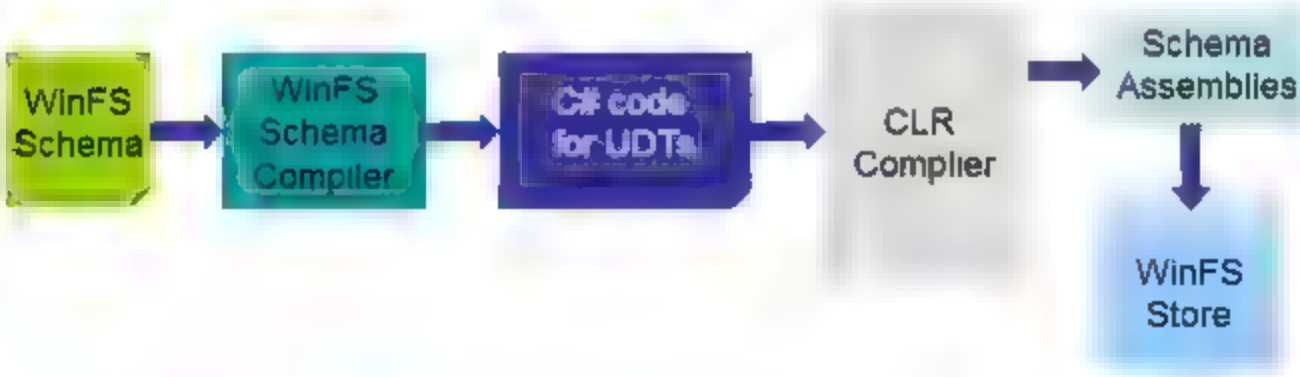
- Current investigating replacing the MultiSet collection with IList<T> (to support ordering)

Schemas

- A WinFS schema defines Item, Extension and Relationship type definitions
- It also defines:
  - Enumerations
  - Views (pre-defined queries)
  - Indexes
- A schema identifies a namespace (CLR)
- The namespace is used to partition types within the WinFS Store and CLR namespace
- The System.Storage namespace defines the root types Item, Extension and Relationship

Schema compilation process

- WinFS schemas are defined using the WinFS schema language (XML grammar)
- The schema compiler generates C# code from the WinFS Schema
- The C# source files are compiled into assemblies
- Two assemblies are generated for each schema – one client and one storage (.Store) assembly
- The Store assembly is installed into a WinFS store
  - WinFS types are registered as user defined types
  - Views and other database objects are created automatically to provide search and storage for the types
  - Clients of the Store are never allowed to issue direct updates against the Store tables/views/etc. They must use the Base API



Schema Type Mapping

- Each WinFS Store is backed by a database
- Each storage schema is installed into a Store:
  - A SQL namespace is created

```
CREATE SCHEMA [System.Storage.Contact.Store]
```

  - The schema assembly is registered

```
CREATE ASSEMBLY [System.Storage.Contact.Store]
FROM ' \System.Storage.Contact.Store.dll'
```

  - Each type in the schema is registered as a SQL UDT
    Sub-types are registered under their parent type

```
CREATE TYPE [System.Storage.Contact.Store].Contact
EXTERNAL NAME System.Storage.Contact.Store. Contact

CREATE TYPE [System.Storage.Contact.Store] Organization
EXTENAL NAME System.Storage.Contact.Store:.Organization
```

Table Storage

- Item, Extension and Relationship types are stored in a single storage table for each type hierarchy

```
CREATE TABLE [System.Storage Store].[Table!Item]
  (_Item [System.Storage.Store].Item,  )
CREATE TABLE [System.Storage.Store].[Table!Extension]
  (_Extension [System.Storage.Store].Extension,  .)
CREATE TABLE [System.Storage.Store].[Table!Relationship]
  (_Relationship [System.Storage.Store].Relationship,  .)
```

- Type instances are stored in object columns _Item, _Extension and _Relationship using type substitutability.
  - For example, Document objects are stored in the column _Item (of type Item)

Type Search Views

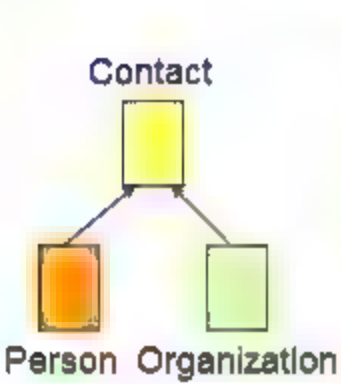
- Item, Extension and Relationship type provides a "master" search view which projects data directly from the storage item/extension/relationship tables

```
CREATE VIEW [System.Storage Store].[Master!Item] AS
 SELECT   FROM [System.Storage.Store].[Table!Item]
CREATE VIEW [System.Storage.Store].[Master!Extension] AS
 SELECT   FROM [System.Storage.Store].[Table!Item]
CREATE VIEW [System.Storage.Store].[Master!Relationship]AS
 SELECT . FROM [System.Storage.Store].[Table!Item]
```

- Each Item, Extension and Relationship type has a type specific view

```
CREATE VIEW [System.Storage.Contact.Store].Contact AS
 SELECT
     Item,
     Item.ItemId AS ItemId,
     Item FirstName AS FirstName,
 FROM (
   SELECT TREAT( Item AS [ ].Contact) as  Item
   FROM System.Storage.Store].[Table!Item]
   WHERE Item IS OF ([ ].Contact)
 ) AS Contact
```

Type Search Views



SELECT … FROM Contact WHERE DisplayName = 'Joe Bloggs'

SELECT … FROM Contact WHERE _Item IS OF(ONLY Contact, Person)

SELECT … FROM Organization WHERE OrgName = 'WinFS'

Type Indexing

- WinFS supports indexing of properties of Item, Extension or Relationship
  - Index on scalar properties Ex: Contact.BirthAddress.Zip
  - Index on collection properties Ex: Contact.Addresses[](City, Zip)
- Indexes are supported using SQL indexed views
- Each index defines a unique index view definition which projects the required columns and filters based on type
- SQL supports fast matching of indexed views including
  - column coverage
  - type inference (index on parent types can be used to match sub-type search)

Type Indexing
Scalar Example

Index on Contact(BirthAddress.Zip)

```
CREATE VIEW [System.Storage.Contact.Store].[IVCtx]
WITH SCHEMA BINDING AS
SELECT ItemId, _SdId, _Item.HomeAddress.Zip AS Zip,
FROM (
  SELECT ItemId, _SdId, TREAT(_Item AS { }.Contact) AS _Item
  FROM [System.Storage.Store].[Table!Item] I
  WHERE _Item IS OF ({ }.Contact)
) AS c

CREATE UNIQUE CLUSTERED INDEX [IVCtxCI]
ON [System.Storage.Contact.Store].[IVCtx](Zip, ItemId)
   INCLUDE (_SdId)
```

Item Domains

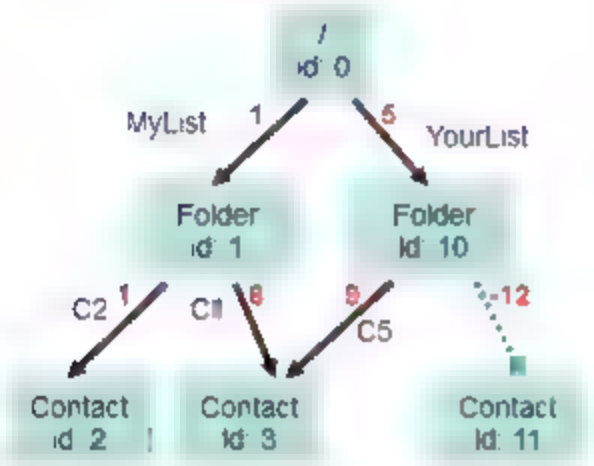
- The item domain of an item defines the closure of items reachable by following holding or embedding links from the item
- Item domains are used to provide search scoping support
  - Implicitly based on the connection point \\machine\winfsstore\path\...
  - Explicitly using rowset functions ItemsInDomain(<itemId>)
- Item domains introduce performance requirements around path closure computation

Item Domains

- The item domain closure in the system is precomputed using a single paths table
- Each path to an item (in the DAG) is represented by a single row in the table
- Each path value is encoded using a packed binary blob called a "PathHandle"

```
CREATE TABLE System.Storage.Store].[Table!Path] (
   [System.Storage.Store].ItemId ItemId NOT NULL,
   [System.Storage.Store].PathHandle PathHandle NOT NULL,
   [System.Storage.Store].PathName Name NULL,    )
```

Item Domains



WinFS Paths Table

ItemID	PathHandle	Logical Path
0	\	\
1	\1	\MyList
2	\1\1	\MyList\C2
3	\1\8	\MyList\C1
10	\5	\YourList
11	\5\ 12	No path (embedded)
3	\5\9	\YourList\C5

Embedding

Holding

- Each relationship is assigned an ordinal
- Embedded items are assigned negative ordinals
- Each path handle is computed by packing the ordinal values from the root to each path

Item Domains

- The descendant limit of a path handle is computable using the function GetDescendantLimit
- A table function ItemsInDomain is defined using the paths table
- This function is applied to all WinFS type views

```
CREATE FUNCTION System.Storage.Store].ItemsInDomain
@pathHandle [System.Storage.Store].PathHandle
RETURNS TABLE AS (
  SELECT ItemId,
  FROM [System.Storage.Store].[Table'Path] p
  WHERE p.PathHandle
    BETWEEN @pathHandle AND DescendentLimit(@pathHandle)
)
```

Item Security

- WinFS provides an ACL security model which implements a superset of the full NTFS security model
- ACL inheritance is propagated along holding relationships
- Each item has an "effective" permission set
- Each security zone is defined by a single column SdId which is added to all storage tables
- WinFS API support for item level security as well as Win32 and Marta integration
- Filtering in views and ItemsInDomain based on security

Item Security

- All read operations (query) are filtered to ensure rows returned are readable by the end-user
- This is done by adding a security check predicate on all search views
- This predicate performs a win32 CheckAccess call on the underlying ACL

```
CREATE VIEW [System.Storage.Contact.Store].Contact AS
  SELECT
     c._Item,
     c._Item.ItemId AS ItemId,
     c._Item.FirstName AS FirstName,
  FROM (
    SELECT TREAT( Item AS [ ].Contact) as  Item,  SdId
    FROM System.Storage.Store].[Table'Item]
    WHERE Item IS OF ([ ].Contact)
  ) AS c
  WHERE c. Item.ItemId IN (   ItemsInDomain(@@item domain) )
    AND has security by sd( SdId)
```

Update API – Manipulating Objects

- The namespace System.Storage.Store provides a core set of procedures for manipulating instances of Item, Extension and Relationship
- All procedures provided in terms of changes to the data model. CreateItem, UpdateItem, DeleteExtension
- Example:

```
-- Remove an extension
EXEC [System.Storage.Store].DeleteExtension @itemId, @extId,

-- Create an Item
EXEC [System.Storage.Store].CreateItem @relationship, @item,
```

Creating an item requires a relationship

Update API – Updating Objects

- In addition to create and delete operations, the Base API provides a granular update mechanism
- This API is utilized directly by the WinFS API
- Clients build a granular change definition (tree)
- This tree is then compiled to return a handle and parameter list
- The handle and parameters can then be used in a call to UpdateItem, UpdateExtension or UpdateRelationship
- UpdateItem et al then produce a batch of granular DML which is used to update the objects in-place

Update API – Updating Objects

- Base uses granular SQL DML to apply changes to the underlying objects
- Example SQL batch:

```
UPDATE [System.Storage.Store].[Table!Item]
SET TREAT(_Item AS [.].Contact).(
    FirstName = TREAT(@cv[0] AS StringVal).Value,
    TREAT(Address AS [.].AddressUk).PostCode
          = TREAT(@cv[1] AS StringVal).Value,
    …)
WHERE ItemId = @itemId AND …

IF @@ERROR != 0 THEN BEGIN
    UPDATE
END
```

- Multiple queries may be required when elements are added, removed and updated to the same collection property

File Support

- Applications can use Win32 APIs to create files in WinFS
- Files can have a metadata handler associated with them by their filename extension
  - If the file content is associated with a handler, the file will be represented as an item of a corresponding WinFS type (ex: Image, Document, AudioTrack, etc.)
  - If the file content is not associated, the file is represented as an item of type System.Storage.GenericFile
- Win32 file and folder attributes are not surfaced in the WinFS data model as schematized properties
  - Stored in separate tables
  - Accessible through Win32 APIs or views [System.Storage.Store].[MasterFileAttributes]

File Support

- File storage in WinFS leverages the SQL "filestream" feature
- Filestreams are exposed as varbinary(max) columns whose binary data is stored in a real NTFS file
  - Give extremely fast streaming access (read/write)
  - WinFS is in the open and close path for file aceess
  - Once a file is opened, the handle is passed off to NTFS
- File stream data and attributes are stored in the File attributes table

```
CREATE TABLE [System. ..Store].[Table!FileAttributes](
  ItemId [ ].ItemId NOT NULL,
  IsSparse BIT NOT NULL DEFAULT(0),
  IsSystem BIT NOT NULL DEFAULT(0),

  Stream VARBINARY(MAX) FILESTREAM,

)
```

WinFS API and Store Integration
Query Example

- Client creates ItemContext to WinFS Store
- Submits find query using Opath
- Object faulted into item context for manipulation

```
using (ItemContext ic = new ItemContext())
{
    ic.Open();
    Contact c = ic.FindItem(
          typeof(System.Storage.Contact.Person),
          "DisplayName == 'Fred Bloggs'");

}
```

- What happened?

WinFS API and Store Integration Query Example

- Client creates ItemContext to WinFS Store
  - SQL Client opens connection
- Submits find query using Opath
- Opath query compiled into TSQL and submitted over SQLClient

```
Contact c = (Contact) ic.FindItem(typeof( Contact),
    "DisplayName == 'Fred Bloggs'");

SELECT _Item, . , ctInfo.UpdateTS as Version
FROM [System.Storage.Contact.Store].Contact c
WHERE c.DisplayName = 'Fred Bloggs'
```

- Store object is returned along with change version number
- API creates a client object and stores in item context

WinFS API and Store Integration Update Example

- Client retrieves object using opath search
- Object available for manipulation in item context
- Client mutates object
- Client saves all item context changes

```
using (ItemContext ic = new ItemContext())
{
    ic.Open();
    Contact c = (Contact) ic.FindItem(
          typeof(System.Storage.Contact.Person),
          "DisplayName == 'Fred Bloggs'");
    c.DisplayName = 'Fredrick Bloggs';
    c.BirthDate = '01/04/1982';
    ic.Update();
}
```

- What happened?

WinFS API and Store Integration Update Example

- Client mutates object
  - Underlying API object setters track object changes
  - API builds ChangeDefinition for updated objects
- Each changed object is enumerated
  - If updated
    - The corresponding change definition is compiled
    - A call is made to the API UpdateItem, UpdateExtension, . .
    - The object timestamp is passed in to ensure correct optimistic concurrency control
  - If deleted – call DeleteRelationship or DeleteExtension
  - If created – call CreateItem, CreateExtension or CreateRelationship
- After each change is submitted to the Store, the item context is updated with the new object version

Recap

- What we've covered
  - WinFS Storage architecture
  - Set of SQL/OR services needed by WinFS
  - WinFS logical data model mapping and physical storage mapping
  - Underlying WinFS service implementation to support indexes, change tracking, notifications, etc
  - API interaction and walkthrough

A Note on Performance

- Significant performance issues with PDC WinFS architecture
  - PDC was a prototype
- Major implementation of underlying system just completed in December
  - Lots of room for performance work
- Q1 '04 major push on performance
  - Code work (in LAB06 in March)
  - "Early look" at how incoming work helps performance
  - Resulted in confidence that performance will be there

WinFS Links and Aliases

- Core WinFS Site http://winfs
  - Links to presentations and team sub-sites
- Email aliases
  - WinFS Questions – discussions of all WinFS related issues
  - WinFS API Discussion – discussions for WinFS API users

Q/A ?